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INSTRUCTION MANUAL

for use with the

"DUCTER"

T. M. REG. U. S. PAT. OFF.

LOW RESISTANCE OHMMETER

Ω

JAMES G. BIDDLE CO.
ELECTRICAL & SCIENTIFIC INSTRUMENTS
1316 ARCH STREET • PHILADELPHIA 7, PA.

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First Edition
February 1948

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CONTENTS

Section — Page

I. INTRODUCTION 5

II. GENERAL DIRECTIONS 7

— Preparation for Test
— Making a Test
— Duplex Hand Spikes
— Single Hand Spikes
— Automatic Cut-out
— Current Leads
— Potential Leads
— Current

III. DIRECTIONS FOR SPECIFIC TYPES 17

— Cat. 713 "Ducter" Instrument
— Cat. 714 and 718 "Ducter" Instruments

IV. COMMENTS ON CERTAIN EQUIPMENT TO BE TESTED 19

— Cable and Conductor Joints
— Useful Formulas
— What Makes a Good Connection
— To Measure Resistance of Long Conductors
— Oil Circuit Breaker Assemblies
— Sources of Trouble
— Procedure
— Rotating Equipment
— Motor Armatures
— Two Methods of Test
— Riser Joints
— Equalizers
— Other Tests
— Transformers and Coils
— Resistance Time-Constant

Section Page

V. BATTERY SUPPLY 29
— Dry Cells
— Alkaline Cells
— Inspection of Alkaline Cells on Receipt

VI. RECTIFIER-OPERATED POWER SUPPLY SET 33
— Cat. 730 Power Supply Set
— Cat. 729 Power Supply Set
— Description
— Operation
— Overload Protection
— Ventilation

VII. PRINCIPLES OF OPERATION OF THE "DUCTER" LOW RESISTANCE OHMMETER 36

VIII. RESISTANCE NETWORK DATA 41
— The Series Network
— The Parallel Network
— The Star Network
— The Delta Network

IX. TEMPERATURE DATA 46
— Resistance Values Corrected for Temperature
— Determining Temperature from Resistance Measurements

"DUCTER" LOW RESISTANCE OHMMETERS

Cat. No.	Scale Multiplier	Ranges In Microhms*	Ranges In Ohms	Value of Each Scale Division In Microhms	Value of Each Scale Division In Ohms	Normal Battery Volts	Normal Testing Amps.	Potential Circuit Ohms†	Max. Current Lead Ohms‡
713 (Scale—0 to 100 Microhms)	10 000	1 000 000	1.00	10 000	.01	1	1	50	.520
	1 000	100 000	.100	1 000	.001	1	1	5.0	.870
	100	10 000	.010 0	100	.000 1	1	1	.50	.860
	10	1 000	.001 00	10	.000 01	1	10	.50	.133
	1	100	.000 100	1	.000 001	1	100	.50	.010
714 (Scale—0 to 1000 Microhms)	1 000	1 000 000	1.00	10 000	.01	1	1	50	.520
	100	100 000	.100	1 000	.001	1	1	5.0	.870
	10	10 000	.010 0	100	.000 1	1	1	.50	.830
	1	1 000	.001 00	10	.000 01	1	10	.50	.139
718 (Scales—0 to 500 Microhms and 0 to 5 Ohms)	Inner		5.0		.1		0.15	25	2.570
	1 000	500 000	.50	10 000	.01	1	1	25	.440
	100	50 000	.050	1 000	.001	1	1	2.5	.720
	10	5 000	.005 0	100	.000 1	1	2	.50	.435
	1	500	.000 50	10	.000 01	1	15	.50	.093

* One Microhm = One Millionth of an Ohm.

† Including .04 ohm resistance of potential leads.

‡ The resistances shown in this column are the maximum permissible total values for the two supply leads between the source of supply and the instrument, plus the two current test leads between the instrument and the resistance under test. These resistance values will reduce the test current by about 50% when the resistance under test is at the full scale value for its range, and should not be used unless long, light-weight current leads are necessary. See page 12.

Section I

INTRODUCTION

The "Ducter" Low Resistance Ohmmeter is one of the famous "Megger"* family of resistance measuring instruments, possessing the features of ruggedness, reliability, and simplicity of operation that are so characteristic of these devices. The Instrument is a direct-indicating, cross-coil true ohmmeter designed for measuring low resistances by the fall-of-potential method. It is intended primarily for field and shop use, where simplicity and speed, at commercial accuracy, are of primary importance. It is usually dependable to within one-half of one per cent of full scale deflection on all of its ranges. See Accuracy, page 37.

Each instrument is supplied with one pair of Cat. 722 Duplex Current and Potential Hand Spikes and Leads, and one pair of Cat. 721 Single Potential Hand Spikes and Leads. See Section II, "General Directions," for the substitution of other leads; and see Section III, "Directions for Specific Types," for the use of the Duplex Hand Spikes with the Cat. 713 "Ducter" Instrument.

When specified, one pair of Cat. 725-L, 727-L or 729-L leads, for connecting the Instrument to its source of supply, are furnished.

The source of supply for "Ducter" Instruments may be one of several types, and may or may not have been supplied with the Instrument depending upon the choice of the purchaser. See Sections V and VI.

The "Ducter" Low Resistance Ohmmeter is practically foolproof if handled wth reasonable care. It is designed to operate with the utmost simplicity, requiring no adjustments whatever, so that an unskilled person can obtain accurate results with little or no knowledge of the Instrument's principles. The following general precautions, however, should be observed:

* Trademark Reg. U. S. Patent Office.

Precautions

— Do not test any equipment while it is energized.

— Do not use more than one cell of a battery (two cells may be connected in multiple).

— Do not use cells in series.

— Be sure the battery is charged.

— Observe proper polarity when making connections.

— When using the multiply-by-1 range (0 to 100 microhms) of Cat. 713 Instrument do not use the Duplex Hand Spikes. Use separate current and potential leads. Also use the Range 1 push-button while taking readings.

— If the automatic Cut-Out on the Instrument operates, determine and correct the cause before resetting it. Do not hold the reset button down after the Cut-Out has tripped.

— Remember that in testing any highly inductive circuits such as transformer windings, the potential spikes should be removed before the tests current circuit is disconnected. This procedure will prevent abnormal induced voltages from appearing across the potential terminals of the Instrument. Such abnormal voltages may be induced across the terminals of the transformer also, when the current circuit is opened. Therefore, remove the current connections from the transformer terminals SLOWLY. It is sometimes advisable to short-circuit the terminals of other windings before removing the current connections to prevent high induced terminal voltages across these other windings, or the winding under test may be short-circuited before removing the current test leads.

— Remember that most metals to be tested change in resistance with temperature.

Section II

GENERAL DIRECTIONS

Refer to Section III for particular Instrument in use.

PREPARATION FOR TEST

1. Place the Instrument on a firm and fairly level base. Avoid large masses of iron and strong magnetic fields. It is usually desirable to set the Instrument with the battery terminals to the left of the operator.

2. The pointer will have a tendency to float towards zero before the current and test connections are made.

3. Check the Range Switch of the Instrument to be in the OFF position.

4. Connect the source of supply, observing polarity marks on the "Ducter" Instrument and the supply. See page 12 of this Section and Section III for capacity of supply leads. See Section V and VI for the operation of the source of supply.

5. Before making connections to the resistance under test, it is good practice to touch the current leads together and note the Instrument pointer, which should move immediately to zero on any range of the "Ducter" Instrument.

6. If the Duplex Hand Spikes are to be used, observe the color code in making connections to the Instrument—red lead to P and black lead to C. If the Single Potential Hand Spikes are used (having red leads), connect them to P.

7. If the Single Potential Hand Spikes are used (which are required when using the 0 to 100 microhm range of Cat. 713 Instrument), first make the current connections from the C terminals to the resistance under test. Then connect the Single Hand Spikes (having red leads) to the P terminals. Observing proper polarity, apply the Potential Spikes to the resistance under test. See further directions in Sec. III.

8. If the supply leads, or the potential leads with respect to the current leads, are reversed in polarity, the pointer will go off scale below zero when connections are made to the resistance under test.

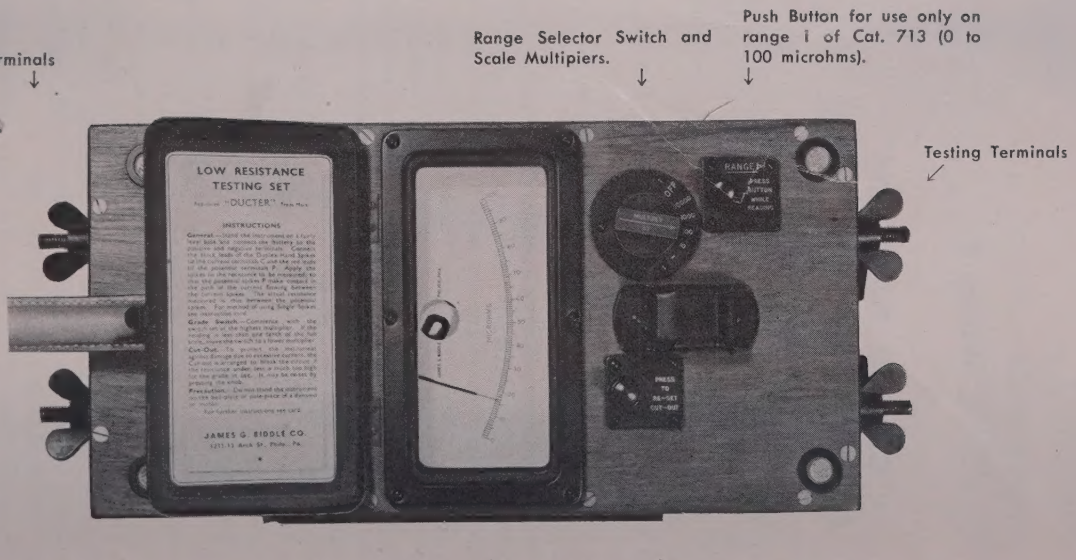
Supply Terminals
Range Selector Switch and Scale Multipiers.
Push Button for use only on range 1 of Cat. 713 (0 to 100 microhms).
Testing Terminals
LOW RESISTANCE TESTING SET
"DUCTER"
INSTRUCTIONS
JAMES G. BIDDLE CO.
RANGE
PRESS BUTTON WHILE READING
PRESS TO RE-SET CUT-OUT
Scale. Read directly and then multiply by the Range Switch Setting.
Push Button to reset cut-out.

FIGURE 1. Top view of Cat. 713 "Ducter" Low Resistance Ohmmeter.

FACSIMILE SCALES

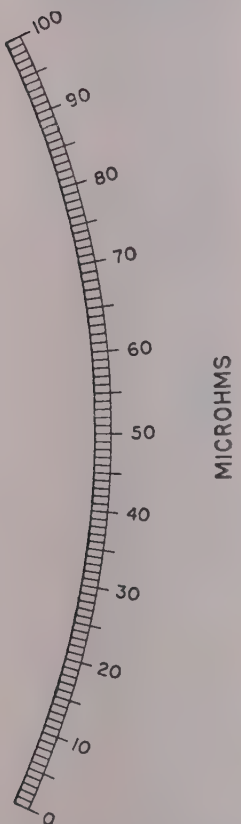

FIGURE 2. Cat. 713. Lowest range 0 to 100 microhms. Highest range 0 to 1 ohm.

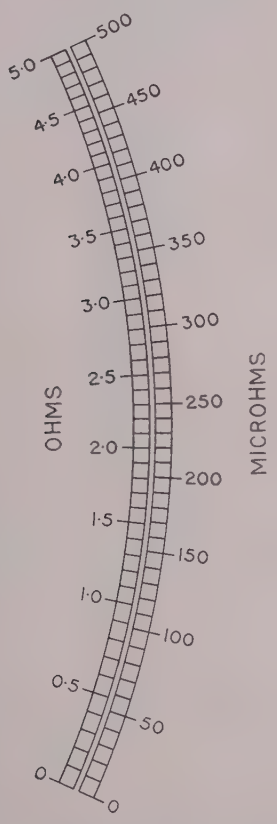

FIGURE 3. Cat. 718. Lowest range 0 to 500 microhms. Highest range 0 to 5 ohms.

Cat. 714 has same scale as Cat. 713, but graduated 0 to 1000 microhms.

MAKING A TEST

If the resistance under test is of an unknown value, start with the Range Switch in the highest position. If the measured value is less than 10% of the full scale deflection, move the Range Switch to the next position, and so on until a maximum deflection is obtained. The reading multiplied by the value of the

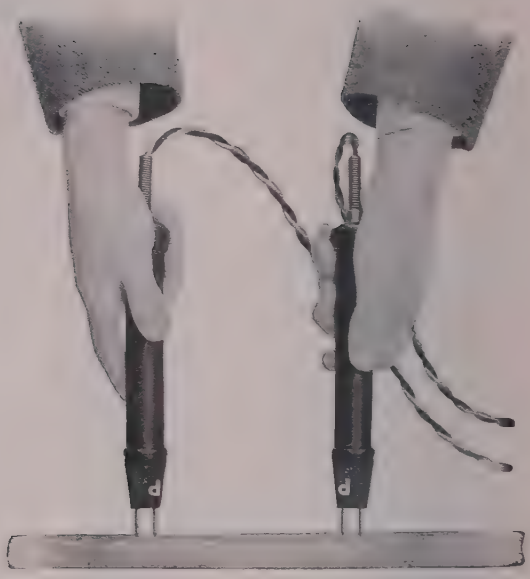

FIGURE 4. Cat. 722 Duplex Helical Hand Spikes for use with any range of "Ducter" Ohmmeter except 0 to 100 microhms. Note that the potential points marked P and P are placed towards each other.

Range Switch setting is the resistance in microhms between the Potential Spikes on the resistance under test. After a reading, or series of readings, it is best to return the Range Switch to the OFF position.

Duplex Hand Spikes

Apply the Duplex Hand Spikes to the resistance which is to be measured, forcing the handles down, causing the spikes to revolve until good contact is made. The current passes through the conductor under test from one Current Spike to the other, and the Potential Spikes must make contact with the conductor in the path of the current. The Potential Spikes are distinguished by the letter P marked on the handle. When the conductor under test has terminals of negligible resistance this precaution may be ignored. The actual resistance measured is that between the Potential Spikes as shown in Fig. 4.

Single Hand Spikes

When the Single Potential Hand Spikes are used, they must be applied to the resistance under test in relation to the current connections in a position as described for the Duplex Spikes. It is often desirable and more convenient to use the Single Potential Spikes and separate current leads in cases where several separate, and possibly changeable resistances, are in series, by probing with the Single Potential Spikes between the current connections. When separate current leads are used and are attached to the resistance to be tested, the Instrument pointer will move to its zero position before the potential prods have been applied.

In testing highly inductive circuits the Potential Spikes should be removed before the test current circuit is disconnected. This procedure will prevent abnormal induced voltages from appearing across the potential terminals of the Instrument. See Section IV, under "Transformers and Coils."

Automatic Cut-Out

The potential circuit of the Instrument is protected against excessive voltage, should the resistance under test be either open or unexpectedly high. This is accomplished by a quick-acting automatic Cut-Out in the current circuit as shown in Figs. 13, 14 and 15.

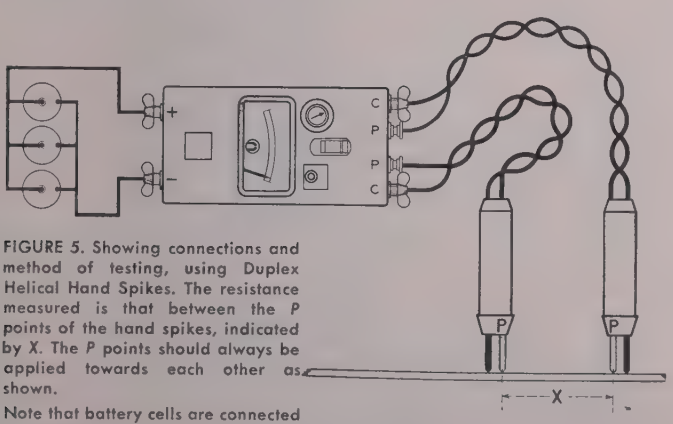

FIGURE 5. Showing connections and method of testing, using Duplex Helical Hand Spikes. The resistance measured is that between the *P* points of the hand spikes, indicated by X. The *P* points should always be applied towards each other as shown.

Note that battery cells are connected in multiple.

This Cut-Out is operated by polarity trip coils across the potential circuit, whenever the potential across the resistance being measured is excessive. An indicator in the scale plate shows whether the Cut-Out is open or closed, and a push-button for resetting it is located nearby on the top of the case. If the Cut-Out is open, the two points in the Cut-Out indicator (see Fig. 1) will be separated. Resetting the Cut-Out, by pushing the reset button, will also close the points of the indicator. The Cut-Out is a safety device, and should operate only (1) if connections are not properly made, (2) if the resistance under test is open, or (3) if the range switch is on too low a setting. Warning: If the Cut-Out has tripped, do not hold down the reset push-button. Investigate the cause and correct the reason for the Cut-Out operation before resetting it.

Current Leads

The resistance of the current leads and their contacts with the resistance under test are not included in the measurement, and therefore, introduce no error unless these resistances are excessive. Ordinarily it is merely necessary that the current leads and their connections be heavy enough to carry their rated current. See Section III, item No. 4. The length of the current leads between the supply and the Instrument can be kept short and their resistances kept down to a negligible value. Therefore, any conductor size that is thermally adequate will be satisfactory. In the event that exceptionally long current leads are required from the Instrument to the resistance under test, then the conductor size should be such that no serious voltage drop results.

However, the conductor resistance between the supply, and through the Instrument, to the resistance under test may be such that the rated test current is reduced by 50% without affecting accuracy *on this account* by more than about 1%. The effect on sensitivity is neglible for a reduction in current up to that value. This means that the total resistance of the current conductors from the source of supply to the Instrument, and from the Instrument to the resistance under test, should not exceed the values given in the Table on page 4, if the accuracy is not to be affected by more than indicated above. In general, it is strongly recommended that current leads be used having total resistances well below these values, so that rated current will be delivered to the resistance under test.

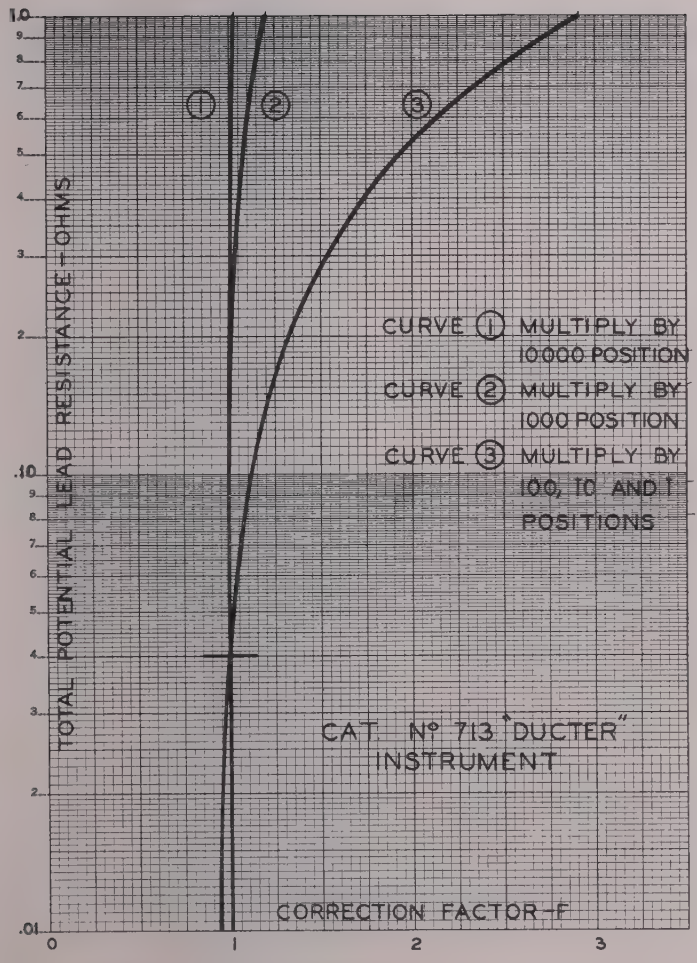

FIGURE 6. Curves showing correction factor to be used as multipliers for readings obtained with Cat. 713 "Ducter" Instrument, using potential leads having a total resistance different from .04 ohm.

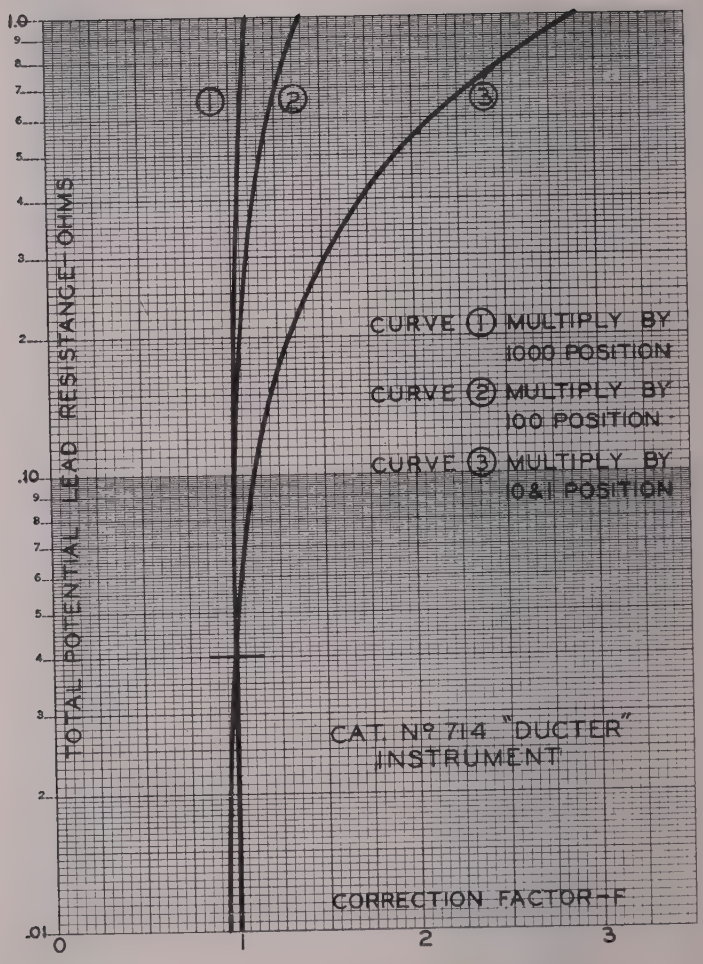

FIGURE 7. Curves showing correction factors to be used as multipliers for readings obtained with Cat. 714 "Ducter" Instrument, using potential leads having a total resistance different from .04 ohm.

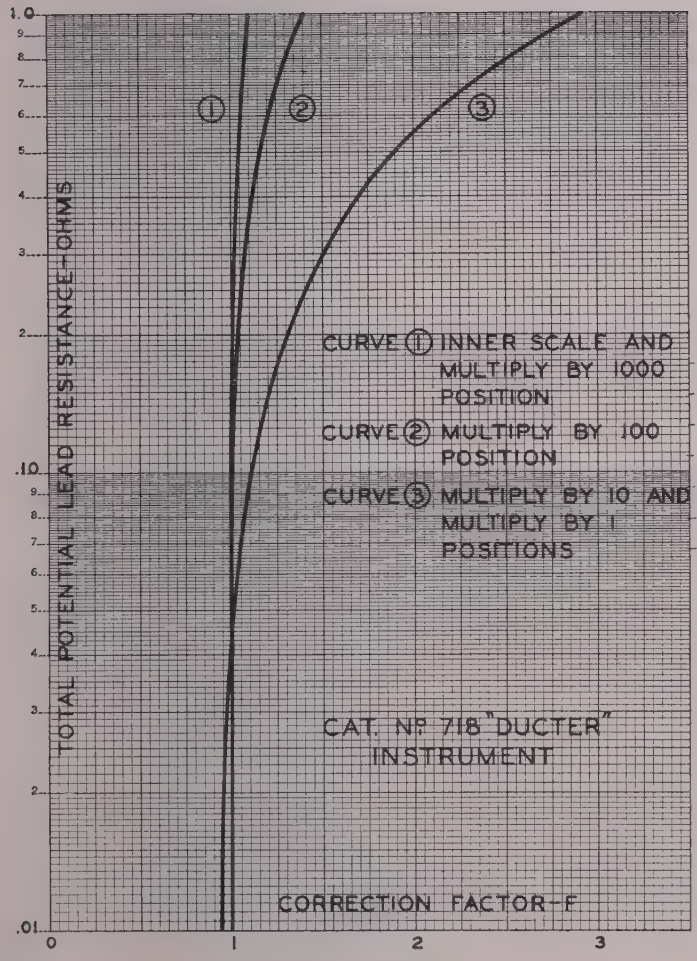

FIGURE 8. Curves showing correction factors to be used as multipliers for readings obtained with Cat. 718 "Ducter" Instrument, using potential leads having a total resistance different from .04 ohm.

Potential Leads

The potential leads, regularly supplied with the "Ducter" Single or Duplex Hand Spikes, each have a resistance of .02 ohm (or .04 for the two leads) and the Instrument is calibrated accordingly. Therefore, if other potential leads are used, they should have a total resistance of .04 ohm. If extra long and light potential leads are required, necessitating a total potential lead resistance in excess of .04 ohm, then a correction factor must be applied to the Instrument readings if accurate results are desired. Curves in Figs. 6, 7 and 8 show the necessary correction factors for potential leads having various total resistances.

Current

The internal resistance for each range in each Instrument is so adjusted that the maximum current which can be drawn from a one-volt supply will be safe for the Instrument, and therefore no current-regulating device or ammeter is necessary. Make sure, however, that the normal current for the range in use will not damage the resistance under test.

Section III

DIRECTIONS FOR SPECIFIC RANGES OF "DUCTER" INSTRUMENTS

Cat. 713 "Ducter" Instrument

Referring to Section I, page 4, it will be noted that the 100 microhm (multiply-by-1) range of this Instrument delivers 100 amperes through the resistance under test. This is necessary in order to obtain the extreme sensitivity of this range, permitting resistance values as low as .000001 ohm (1 microhm) to be measured.

Because of the relatively high current used for this range, several points in addition to those listed in Section II, page 7, must be considered in the use of the No. 713 Instrument as follows:

1. The battery or rectifier-operated power supply must be of ample capacity to deliver 100 amperes without an appreciable voltage drop. See Sections V and VI.

2. The connecting leads from the source of supply, together with the current leads between the Instrument and resistance under test, must be of ample current carrying capacity to deliver 100 amperes without undue heating or excessive voltage drop. The resistance in any case should not exceed a total of .010 ohm for both pairs, and should never be smaller than No. 4 Awg. See Sections I and II.

3. The Duplex Current and Potential Hand Spikes are not intended for use with the multiply-by-1 range of this Instrument, since the leads and flexible connections to the revolving current spikes do not have sufficient current-carrying capacity for 100 amperes. For measurements involving the use of the multiply-by-1 range of this Instrument, use the Single Potential Hand Spikes, and separate current leads as described in paragraph 2. Current leads with open lugs for the Instrument end, and C clamps or toggle clamps for the test end, can be made up to suit local needs.

4. For Range 1 (multiply-by-1) position of the Range Selector Switch a push-button-operated switch is provided to avoid unnecessary drain on the battery when using this range. This switch is in the main current circuit of the Instrument only when the Selector Switch is in the multiply-by-1 position (range 0 to 100 microhms), and must be depressed manually in order to obtain a reading. Readings are obtained on all other ranges without using the push-button.

In testing highly inductive circuits on this range, the push-button should not be released until the Potential Hand Spikes have first been removed. This procedure will prevent abnormal voltages from appearing across the potential terminals of the Instrument. See Section IV, under "Transformers & Coils."

Cat. 714 and Cat. 718 "Ducter" Instruments

No instructions are required for the operation of these two types beyond those listed in Section II.

The Duplex Current and Potential Hand Spikes are intended for all ranges of both Instruments. The battery capacity requirements are low (see Sections V and VI), and the supply leads may be small in size. See Section II. In cases where the Single Potential Hand Spikes are used, the current leads to the resistance under test may be small. See Table in Section I and Section II.

Section IV

COMMENTS ON CERTAIN TYPES OF EQUIPMENT TO BE TESTED

CABLE AND CONDUCTOR JOINTS

High-resistance joints in cables and conductors are a major source of trouble in electrical circuits, and one of the chief uses of the "Ducter" Low Resistance Ohmmeter is in combatting such conditions. High-resistance joints cause objectionable voltage drops, loss of power, and damage from localized heating. A few mental excursions into Ohm's Law will reveal the fact that a small fraction of an ohm in high-current circuits can equal an appreciable number of volts, and will result in lost kilowatts. Circuits normally having low resistances, say in the order of 11,000 microhms (.011 ohm), which is equivalent to about 1,000 feet of 1,000 mcm cable, could easily have defective joints that would double that value. If this cable is rated at 370 amp., the voltage drop would be 100% above normal, or a total of 8 volts, and would waste 36 kwhrs per 24-hour day above the normal loss.

Such defective joints can be discovered by evidences of heat, or by measuring the voltage drop during normal load periods. These methods are not as simple as measuring the cold resistance of the joints, either when they are installed or during off-load periods. Any well-made joint should have a resistance between the points measured not greater than the same length of the cable or conductor involved. This would mean, in the case of the 1,000 mcm cable previously mentioned, that any joint in its length within a space of one foot should not exceed 11 microhms (.000011 ohm). The "Ducter" Low Resistance Ohmmeter measures values down to 1 microhm (.000001 ohm).

Useful Formulas

The foregoing value of 11 microhms is determined as follows:

$R = \rho \frac{l}{a}$ where $\rho = 10.7$ ohms/cm.ft. at 20° for 97% conductivity copper. $l =$ length. $a =$ area.

$$R = \frac{10.7 \times 1}{1{,}000{,}000} = .0000107 = 10.7 \text{ microhms.}$$

This calculation is given here for convenience so that users may be reminded of the method of determining the resistance of any conductor. The following formulas will also be helpful.

Rectangular or square-shaped conductors:

$$\text{Circular mils} = \text{cm} = \frac{\text{sq. mils}}{.7854} = \frac{\text{in.}^2 \times 10^6}{.7854}$$

For round conductors:

$$\text{Circular mils} = \text{cm} = (\text{dia. in mils})^2$$

What Makes a Good Connection

In making low-resistance connections or joints in electrical conductors, the cleanliness of the contact surfaces cannot be over-emphasized. It can be demonstrated that the thinnest film of oxidation or corrosion can affect the resistance of the joint greatly. Furthermore, the electrical resistance of an unfused metallic joint is a function of contact area and pressure, as well as cleanliness. In the case of fused joints the resistance is controlled by the area and effectiveness of the bond. The "Ducter" Low Resistance Ohmmeter is used widely in controlling these variables.

In the discussion of conductor joints it can be mentioned that the "Ducter" Instrument is also used to a great extent in checking the resistance of metallic conduit and structural joints, in those cases where the conduit or steel work is used as a conductor in returning current to the neutral of the source of supply.

To Measure Resistance of Long Conductors

Occasions arise where it is desirable to determine the average copper temperature of cables or conductors, or to measure the resistance of each conductor in a circuit as a check on the condition of inaccessible joints. In such cases it is usually impra-

tical to measure the resistance between the terminals of the circuit because of the distances involved.

The alternative of course is to tie two conductors of the circuit together at the far end, and measure the resistance of the two in series. This allows the average resistance of the two conductors to be determined. If the circuit is a single conductor one having a ground or rail return, then the only alternative is to use a conductor of an adjacent circuit for the test. In that event, the resistance of the conductor used to complete the circuit for test purposes must be known for some particular temperature beforehand if reliable results are to be expected.

In all cases, the resistance of the temporary jumper, including its contact resistances, at the far end must be determined unless they are known to be negligible.

If three or more conductors are available in the circuit, then they may be connected together in groups of three at the far end, forming a star resistance network. By measuring the resistance of the three legs in pairs the resistance of each individual conductor can be readily calculated. See Section VIII.

OIL CIRCUIT BREAKER ASSEMBLIES

The "Ducter" Low Resistance Ohmmeter is used extensively in checking electrical contacts and joints throughout oil circuit breakers, from the top-terminal of one bushing, through the main and auxiliary contact assemblies, to the top-terminal of the associated bushing. Several joints and contacts are included in this circuit which may give trouble.

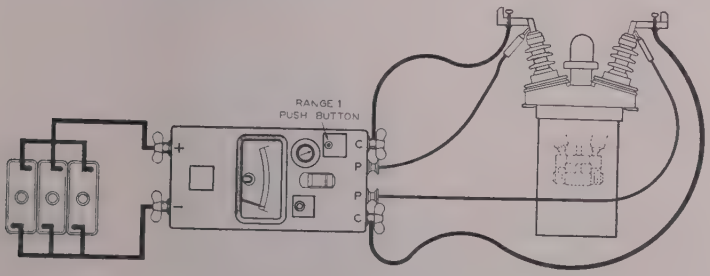

FIGURE 9. Showing connections for testing circuit breaker contacts. This figure also shows connections when using Range 1 of Cat. 713 (0 to 100 microhms). The resistance measured is that through the breaker between the potential hand spikes. These should always be placed inside the current connections.

The frequency of dropping or entering oil tanks of large oil circuit breakers is governed by operating experience, economics, the frequency of fault operations, and the ratio of the fault energy interrupted to the breaker interrupting capacity. The frequency will usually vary from every six months to every two years, depending upon local conditions. A method that will permit the maintenance engineer to feel reasonably sure that no mechanical or electrical faults exist within the tank, without exposing the parts to visual inspection, is definitely economical. The "Ducter" Low Resistance Ohmmeter provides a method for doing this by detecting abnormal resistances within the breaker when it is in the closed position.

Sources of Trouble

Numerous types of bushing top-terminals and top-terminal assemblies are to be found in service, many of which have been known to give trouble from over-heating if not properly assembled.

The center or conducting rod, or tube through the bushing itself, is usually one continuous piece attached to the top-terminal assembly by a fused or unfused mechanical joint, and the resistance of this joint will depend upon design and workmanship.

The contact assembly at the bottom of the bushing's center conductor is mechanically attached to permit ready adjustment or removal, and again the resistance of this joint will depend upon design and workmanship.

The movable-contact assembly, made up of the bridging or cross-member, main contacts, and auxiliary (arcing) contacts, has joint resistance values which vary depending upon design and assembly workmanship, aside from the actual contact resistance between the stationary and movable members.

The component parts of the bushing top-terminal assembly, together with those of the stationary and movable contact assemblies, are usually non-ferrous castings, and sometimes develop cracks as a result of misalignment or undue strain. These failures usually affect the overall resistance of the "closed breaker" total resistance and can be detected by "Ducter" Instrument measurements.

The auxiliary and main contacts themselves, both movable and stationary, oftentimes complete the electrical circuit through braided or leaved flexible bonds or jumpers which are

Table I

MAXIMUM CIRCUIT BREAKER CONTACT RESISTANCE VALUES AS ESTABLISHED WITH THE "DUCTER" LOW RESISTANCE OHMMETER

(As measured at the bushing terminals.)

Circuit Breaker Type	KV.	Amps.	Max. Allowable Resistance Microhms OCB Closed
FH 6	15	600	300
FH 203	15	600	300
FH 206	15	600	200
FH 206	15	3000	30
FH 209	15	2000	50
FHB-123	15	600	300
FHB-123	15	1200	100
FK2	7.5	300	1000
FK12	15	500	200
FK-53B*	15	2000	50
FK-230-16A	15	600	300
FK-330-16A	15	600	300
FKR-132B	15	600	200
FHK-130-20B	15	600	300
FHK-130-20B	15	1200	100
FHK-130-28B	15	3000	50
FHK-230-20B	15	600	300
FHK-230-28B	15	3000	50
FHK-330-20B	15	600	300
FHO-136-1026AS	25	400	400
FHO-136-1026AS	25	800	300
FHKO-39-32BS	37	400	600
FHKO-39-48BS	73	400	600
FHKO-39-60CY	73	1200	280
FHKO-139-24AS	15	2000	75
FHKO-139-24BS	15	800	300
FHKO-139-24BS	15	1200	200
U Deion	15	600	200
150U12	15	600	100
150U22	15	600	100
D13 B	15	600	200
Silverplated	15	600	150
D13 C	15	600	200
D17 B	15	800	250
DR 40	15	1200	100
DR 60*	15	1200	100
F 8	15	600	200
F 120	15	600	200
F040A	15	600	200
F040A	15	1200	150
F040C	34.5	600	200
02	15	600	200
02	15	1200	150
Y-1*	15	2000	50
FHKO-139-36CS	15	4000	40
FHKO-139-54CY	73	800	400
FHKO-139-60CYF73	73	1200	300
FHKO-139-114CY	187	1000	500
B-7A	15	2000	50
B-13	7.5	600	100
CO	15	600	200
CO-11	15	1200	150
CO-111	15	1200	150
E-17	15	2000	50
G1	25	400	600
G-11	37	600	200
G-22-2	73	800	350
G-222	187	1000	350
G-222A	73	800	350
G-222S	187	1000	350
G03	15	600	200
G22	15	2000	50
O-241	15	600	200
O-241	25	2000	100
O-331	15	2000	75
O-331 S	25	2000	75
FHKO-239-108CY	230	1000	500

* Circuit breaker contacts are silver plated.
Any breakers that cannot be made to conform to these values should be investigated.

flexed during opening and closing operations. The fraying or breaking of the strands or leaves of these jumpers can be detected by an increase in the "closed breaker" total resistance.

The contact resistances of the main and auxiliary contacts, because of their function, are naturally the most common variables. Burning and carbonization of these contacts under arcing conditions, when allowed to become aggravated, eventually increase the contact resistance to such an extent that the heat caused by current further carbonizes the oil between the contact surfaces, thus causing a cumulative action.

Procedure

To determine the condition of the contacts by the resistance measurement method, the resistance should first be measured with the breaker fully closed. This measures the resistance of the main and auxiliary contacts in parallel.

The breaker is then unlatched and allowed to open slowly until the main contacts have parted, thus measuring the resistance of the auxiliary contacts only.

The normal resistance of circuit breaker contacts varies considerably in different types of breakers ranging from about 30 to 1,000 microhms. One of the larger eastern public utilities has been accumulating oil circuit breaker contact resistance data since 1940, which data have been analyzed for both the "as found" and "as left" condition of the contacts. A summary of conclusions as to maximum allowable contact resistances are listed in Table 1. Additional data for other types of oil and air blast circuit breakers is being compiled throughout the country.

What has been said about the method of analyzing conditions in oil circuit breakers applies equally to air circuit breakers of the various types, and to a great extent, disconnecting switches, air-break switches, and knife switches.

ROTATING EQUIPMENT

One of the most common uses of the "Ducter" Low Resistance Ohmmeter is the bar-to-bar testing of d-c and commutator-type a-c armatures. These tests are made primarily for two reasons—(1) to reveal shorted commutator bars, shorts in armature coils, and shorts between equalizers or cross connections; and (2) to reveal high resistance joints between commutator bars and risers, risers and coil ends, and coil back-end connec-

tions. Of the two, the latter is the more common source of trouble.

Motor Armatures

Experience has shown that periodic tests on all types of series traction motor armatures are well justified—types such as crane, mill, surface and subway car, trolley coach, and MU car motors. The practice establishes the bar-to-bar resistance value of the new or correctly rewound armature, and detects any increase in riser-joint resistances resulting from overload or faulty fields.

The Duplex Hand Spikes are ideally suited for making bar-to-bar tests on all armatures, with the possible exception of extremely small commutators in the fractional horse-power class. The spikes may be applied either at the edge or the neck of the commutator, depending upon whether short circuits between bars, or high-resistance joints are to be investigated. Ordinarily, the bar-to-bar resistance of armatures will fall in the 1,000 or 10,000 microhm range of the "Ducter" Instrument.

Two Methods of Test

Either of two methods may be used in making armature measurements—one the direct comparison method, and the other the direct reading method. The direct comparison method assumes no knowledge of the resistance of the separate coils, and simply involves taking measurements between all bars and noting any marked deviation from the average. Deviations beyond 5% are worthy of investigation.

The direct-reading method involves the measurement of the actual resistance of a good spare coil to establish a definite minimum bar-to-bar value at the same or corrected temperature. For a simplex, wave (series) winding the number of coils in series between adjacent bars will equal the number of pairs of poles.

For simplex, lap (parallel) windings the number of coils included between adjacent bars is always one, regardless of the number of poles. If either the wave or lap winding is of the double or duplex type, the circuit will be completed for testing purposes through the first and third bars rather than adjacent bars.

In the direct reading method, the Duplex Prods are usually applied at the riser end of the commutator to eliminate the resistance of the commutator bars. However, the normal individual bar resistance can be determined separately, and included with that of the separate coil to establish a minimum value. The prods would then be applied to the commutator edge, and any excess resistance over that figure would be caused by joint resistance.

Riser Joints

In investigating riser-joint resistances it is sometimes advisable to apply the prods directly across the riser joints themselves, i.e., one prod at the commutator neck and the other at the coil end. The Duplex Prod's revolving points are especially suitable for making contact through paint and varnish into the risers and coil ends. Thus it is possible to compare the resistance of joints between commutator bars and risers, or between risers and coil ends at the front end of the armature, or between backends at the rear of the armature.

Equalizers

Lap-wound armatures having equalizers or cross-connections increase the complexity of the network of parallel paths. In one method of winding equalized lap-wound armatures, the cross-connections are made behind the commutator risers; and in another method they are made at the back end of the armature coils. The pitch of the cross-connection is the number of commutator bars divided by the number of pairs of poles.

Therefore, to test the resistance of equalizers the Duplex Prods should be applied to the bars having known cross-connections, and spaced over the number of bars representing that pitch. If the equalizers are connected at the risers the measurement will include the resistance of the equalizer jumper and its joints in parallel with the ring or jumper of the same group in the opposite direction around the armature. Armature coils are also in parallel with these circuits and will lower, to some extent, the measured resistance. If the equalizers are connected at the back end, two half-coils and their joints will be included in series with the equalizer jumper or ring section involved, unless the Duplex Prods are applied to the back end.

It is suggested that reference be made to standard textbooks*

* See "Connecting and Testing Direct Current Machines," Annett & Ree McGraw-Hill.

on armature practices for further information concerning networks involved in the several types of armature windings.

Other Tests

The "Ducter" Instrument is also useful in detecting abnormal or unbalanced resistances in other parts of rotating equipment, such as joints between studs and collector rings in rotary converter armatures, and wound-rotor induction motors. The resistance from brush holders, through the brush arm, to the brush-arm bracket of d-c motors and generators should be balanced to prevent an unequal division of current between brush arms and holders of the same polarity.

Series field circuits of d-c rotating equipment and a-c traction motors should be kept to normal values to prevent localized heating in joints and connections. Similarly, the salient and cylindrical-pole fields of synchronous equipment, such as condensers and alternators, may develop defective joints or shorts between turns that may cause trouble from localized heating if allowed to continue.

TRANSFORMERS AND COILS

The measurement of the winding resistances of transformers and of coils is comparable to that of any other electric circuit, with one exception. Such windings have inductive characteristics, as well as d-c resistance.

In a complete transformer, fused winding joints, tap-changer contacts, and bushing assembly joints are included in the test, and must be considered when analyzing conditions.

The resistances of the low-voltage windings of power transformers will ordinarily be less than one ohm, and any of the three available "Ducter" Instruments may be used in such cases. However, the resistances of the high-voltage windings of most power transformers, unless they are of large capacity, will usually exceed the 5 ohm maximum value available with the highest range Cat. 718 "Ducter" Instrument.

Resistance Time-Constant

When the d-c potential of approximately one volt is applied to a transformer winding or coil during a "Ducter" Instrument test, the length of time for the current to build up to normal, based only on the d-c resistance of its copper, is dependent upon the time-constant of the circuit. In other words, it depends

upon the resistance in ohms and the inductance in henrys of the complete test circuit, and may ordinarily require several seconds. This fact is not too important since the time required to reach stable conditions ordinarily adds very little to the testing time. The one justification in mentioning it is to remind the tester that he should wait until the pointer of the "Ducter" Instrument comes to final rest before taking a reading. The foregoing assumes that the other transformer windings are open-circuited. If any other magnetically coupled winding or windings are short-circuited at the time the voltage is applied, then the time required to reach stable conditions will be greatly increased.

Important

When dealing with inductive circuits it is of utmost importance that the test current circuit should not be allowed to become disconnected until after the reading has been taken, and *only after the potential prods have been removed.*

Large power transformers with a considerable number of turns may have appreciable inductances, and if the current test circuit is broken instantly, before the potential prods have been removed, a high voltage will appear across the *P* terminals of the Instrument.

Even after the potential prods have been removed, the current connections at the terminals of the transformer under test should be removed SLOWLY before any other point in the current test circuit is disconnected, otherwise a voltage may be produced which will be dangerous to the equipment being tested, or to the persons involved in the test activities. Furthermore, if the winding or windings not being tested are open-circuited at their terminals, a voltage in proportion to the turn-ratio of the windings will be produced at these terminals. It is often advisable to short-circuit the winding under test, or the other windings, before disconnecting the current test leads.

Section V

BATTERY SUPPLY

The "Ducter" Low Resistance Ohmmeter is designed to operate from a one-volt d-c supply. It is not intended to be used with a lead-acid storage battery since the voltage output of this type of cell is somewhat higher than one volt. This higher voltage will result in a current flow through the Instrument in excess of the rated currents listed in the Table in Section I, thereby affecting the accuracy of the measurement to some extent, and exceeding the thermal capacity of the Instrument. Although the practice of using lead-acid batteries with "Ducter" Low Resistance Ohmmeters is not recommended, some companies are using them for certain applications with satisfactory results.

Dry Cells

Referring to the Table in Section I it will be noted that currents as low as .15, 1, and 2 amperes are normal currents for several ranges of the three Instruments. For these ranges standard No. 6 dry cells may be used, either singly or grouped in parallel.

Alkaline Cells

For general testing where any range of the "Ducter" Instrument may be brought into use, nickel-iron-alkaline storage batteries are recommended. The James G. Biddle Company makes available Edison Cells of this kind when specified. Two are available and recommended, the Edison Type A6 for the Cat. 713 "Ducter" Instrument, and the Edison Type B4 for the Cat. 714 and 718 "Ducter" Instruments.

Thomas A. Edison, Inc., supplies their bulletin 850X with each Edison Battery which gives all necessary instructions and information for their operation and care.

For the benefit of those who may not have this bulletin available certain instructions and information are excerpted as follows:

Type of Cell	Amp. Normal Charge & Discharge Rate	Amp.-Hr. Capacity Normal Rate	Hr. Normal Charge from Completely Discharged Condition	Pounds Renewal Solution for One Cell
A6	45	225	7	4.39
B4	15	75	7	1.94

Low-rate charging has no permanent effect on Edison Cells, nor has it any very appreciable immediate effect when the discharge is also at a low rate. However, when it is desired to discharge continuously at normal rates or above, low rate charging will cause an immediate loss of capacity. This is due to the fact that low rates will not completely reduce the iron or negative electrode, or in other words, charge the battery. Therefore, it is obvious that normal-rate charging either on the constant-current or the average-normal basis is essential to efficient operation continuously. In other words, it is recommended that alkaline cells be charged at normal rates, as the best chemical reaction is obtained under these conditions.

When an Edison Battery does not give satisfactory capacity on discharge at rates several times normal, it is considered sluggish. This sluggishness or low capacity may result from persistent low-rate discharging, frequent low-rate charging, long stands, seldom discharging completely, or from weak solution. With the exception of the last named, the primary cause is lack of work. Edison Batteries thrive on work. To restore sluggish cells, completely discharge them at normal rates to zero, and then place the cell on short-circuit for two hours.

Follow this by an overcharge. If sluggishness persists the cycle should be repeated. In the worst cases, satisfactory results can usually be obtained by several such cycles.

Inspection of Alkaline Cells on Receipt

Edison Batteries are all thoroughly formed at the factory, after which they are shipped in either a charged or discharged condition.

A red label, included with the battery in each shipment, indicates that the cells are charged ready for immediate use.

Upon receipt of the battery, inspect each cell for solution height. Use the glass tube furnished for this purpose. Do not use a match or other open flame for inspection.

Electrolyte has been spilled if the tubes are visible above the surface of the liquid, or if the inside of packing case shows yellowish stains. The loss must be replaced, preferably with Edison Storage Battery "Standard Refill Solution," or lacking this, with "Standard Renewal Solution." The proper height of solution for each type of cell is ½".

When the level of solution is only a small amount below the proper height, fill with distilled water, and in the future use distilled water for replenishing the solution.

Carefully remove from the exposed poles any grease or dirt.

The positive pole of an Edison Cell is designated by a red bushing around the pole and plus (+) stamped on the cell cover.

The negative pole is designated by a black bushing around the pole; no designating mark is on the cover.

A loose or dirty contact on a cell pole will cause excessive heating, and may be detected by feeling the connectors during service conditions.

To disconnect cable lugs, first remove nut from each pole. A disconnecting jack is shipped with each battery. This jack is designed to straddle the pole and engage the lug, thereby removing it by screw-jack action.

CAUTION: Never put lead battery acid into an Edison Battery, or use utensils that have been used with acid.

Never bring a lighted match or other flame near a battery.

Never lay a tool or any piece of metal on a battery.

Always keep the filler caps closed except when necessary to have them open for filling.

Keep batteries clean and dry externally.

Edison electrolyte is injurious to the skin or clothing and must be handled carefully. Solution spilled on the person should be immediately washed away with plenty of water.

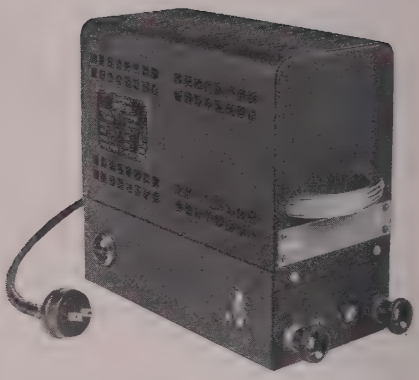

FIGURE 10. Cat. 730, D-C Power Supply.

FIGURE 11. Cat. 729, D-C Power Supply.

Section VI

RECTIFIER-OPERATED POWER SUPPLY SET

Some applications of the "Ducter" Instruments are more conveniently conducted with a rectifier type of power supply than with a battery. The Rectifier-Operated Power Supply Sets made available by the James G. Biddle Company are specially designed for use with "Ducter" Low Resistance Ohmmeters, and it is strongly recommended that they be used in preference to any other rectifier type of power supply which may be available to the user. There are two models of Power Supplies now offered: (1) Cat. No. 730 having a 10 ampere continuous rating at one volt d-c to be used with Cat. 714 "Ducter" Instrument, and (2) Cat. No. 729 having a continuous rating of 10 amperes and an intermittent rating of 100 amperes at one volt d-c for use with Cat. 713 "Ducter" Instruments. Both Models are of the selenium dry rectifier type and are rated for ambient temperatures up to 35° C. They are equipped with supply cords for connection to 115-volt, 60-cycle a-c circuits, and with flexible insulated cables 5 feet long to connect the Power Supply to the "Ducter" Instrument.

CAT. 730 POWER SUPPLY SET

This Supply is for use with all ranges of the Cat. 714 "Ducter" Instrument, and no further instructions other than those furnished on the case of the Supply are necessary. This Supply may also be used with Cat. 718 "Ducter" Instrument, provided the latter has had certain adjustments at the time of its purchase or by its subsequent return to the factory.

CAT. 729 POWER SUPPLY SET

Description

This Supply is for use with all ranges of the 713 "Ducter" Instrument, i.e.—1, 10 and 100 amperes. It has two output ratings—a combination 1 and 10 ampere output which automatically adjusts itself by a small compensating shunt, and a high output of 100 amperes which must be manually set through a push-button operated relay.

On the low rating (1 and 10 amperes) the Supply is capable of continuous operation. The 100-ampere rating may be used for two continuous minutes out of every 15 minutes cooling time. Thermal Cut-Outs which disconnect the voltage source are built into the Supply and prevent overheating the rectifier stack. This operation is indicated by lighting a red pilot. When the OFF-ON switch is operated a green pilot marked CIRCUIT CLOSED is lighted. The OFF-ON switch should be turned to the OFF position when an overload operation occurs, and the rectifier allowed to cool.

Operation

To set the Supply for the low rating (1 and 10 amperes) no further instructions other than those furnished on the case of the Supply are necessary.

To set the Supply for the 100-ampere rating it is first necessary to make the connections between the Supply and the "Ducter" Instrument, and the resistance under test. Also have the potential hand spikes connected and ready for application. Next, the push-button for the current switch on the "Ducter" Instrument is depressed and held down, after which the 100-ampere rating push-button switch on the Supply is pressed momentarily. This closes and latches the high-rating relay in the Supply. The ammeter in the Supply will indicate that normal test current of about 100 amperes is flowing through the resistance being tested. If the current circuit to the resistance under test is opened for any reason, the relay in the Supply will automatically unlatch and restore the Supply to the low-rating position. This feature makes it necessary for the push-button on the Cat. 713 "Ducter" Instrument to be depressed continuously until the test has been completed.

After the foregoing steps the potential prods are applied to the resistance under test to make the resistance measurement.

If the resistance under test is a circuit of high inductance it is important that the potential prods be removed from the circuit before the push-button on the "Ducter" Instrument is released. Unless this is done a high induced voltage may appear across the P terminals of the "Ducter" Instrument.

Overload Protection

Due to greater thermal lag on the 100-ampere rating, compared to the 10-ampere rating, two thermal switches are necessary. If the 10-ampere rating is operated continuously for approximately ten minutes the 100-ampere rating thermal switch opens. This does not affect the 10-ampere rating, but it does prevent using the higher rating until the unit has cooled sufficiently. If the latching relay for the higher rating is then set at this time the operator cannot return to the 10-ampere rating, but must wait for the high rating thermal switch to close. If the high rating thermal switch opens when 100 amperes is being drawn, it is necessary to wait for the rectifier to cool before using either rating.

Should the high rating be in use and the test specimen be highly inductive, a higher-than-normal voltage may appear at the terminals of the Supply when the thermal switch opens. This will trip the latching relay, and transfer the Supply to the 10-ampere rating, thereby making the Supply operative at 1 or 10 amperes. In this event the operator should press the reset button, returning the Supply to the 100-ampere rating, and wait the required time for the thermal switch to close.

The red overload pilot will light only when the thermal switch opens for the rating which is operating. When the red light appears turn off the Supply, and allow it to cool until the red light does not appear when the OFF-ON switch is returned to the ON position.

Ventilation

For best performance place the Supply in a well-ventilated location. For tests of long duration, blocks under the feet of the case, to permit greater air circulation up through the rectifier stack, are helpful.

Section VII

PRINCIPLE OF OPERATION OF THE "DUCTER" LOW RESISTANCE OHMMETER

The well-known d-c fall-of-potential method of measurement is employed in the "Ducter" Low Resistance Ohmmeter; but instead of using separate current and voltage measuring instruments, the result is indicated directly by a cross-coil true Ohmmeter.

As shown in Fig. 12, the moving system of the Ohmmeter consists of two coils mounted rigidly together on a common axis in the field of a permanent magnet. There are no control springs as in an ammeter or voltmeter. Instead, current is led to the ohmmeter coils by flexible conducting ligaments which exert only slight torque, so that when the Instrument is approximately level, and with nothing connected, the pointer will float towards zero.

Current in the current coil is proportional to that through the resistance under test and tends to move the pointer to zero on the scale. This coil is the control coil and its action is similar to that of a restraining spring.

Current in the potential coil is proportional to the voltage drop between the potential contact-points across the resistance under test, and tends to move the pointer to the top of the scale. This coil is the deflecting coil. The final position of pointer is therefore dependent upon the balancing of the opposing forces exerted by these two coils and the scale is marked directly in ohms or fractions of an ohm.

The true Ohmmeter of the "Ducter" Instrument is independent of the exact voltage of the supply used for the test, because any reasonable change in the supply voltage affects both Ohmmeter coils in the same proportion. The pointer, therefore, remains in the same position for a given resistance under test, and no rheostat or other current-regulating device is necessary

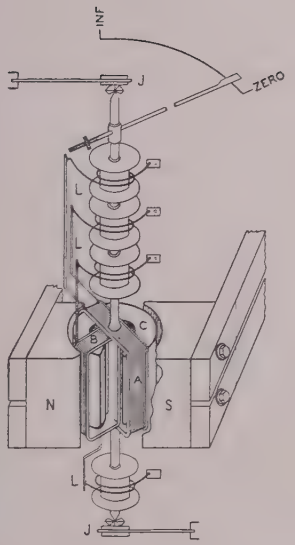

FIGURE 12. Showing diagrammatically the moving system and magnetic structure of the "Megger" true ohmmeter.

A =potential coil

B =current coil

LLL =ligaments hung loosely around insulating spools

JJ =spring-supported jewel bearings

NS =permanent magnet

C =C-shaped iron core mounted in a fixed position coaxially with the moving system

The supply voltage can even change while a test is being made and there will be no movement of the pointer, unless the circuit under test happens to be highly inductive. The current for any range is limited to a safe amount by resistances in the Instrument. This holds true for supply voltages up to 1.5 volts.

The "Ducter" Instrument is compensated for ordinary temperature changes in all of its ranges.

This applies only to the Instrument itself, and not to the resistance under test. See Section IX.

Accuracy

The "guaranteed" accuracy of "Ducter" Instruments when they leave the factory is "within 1% of full scale deflection." Before shipment to our customers they are adjusted to within $\frac{1}{3}$ of 1% and are found dependable in use—barring accident—to within $\frac{1}{2}$ of 1% of full scale deflection. Any check for accuracy must naturally be made at normal voltage and current as per the table on page 4.

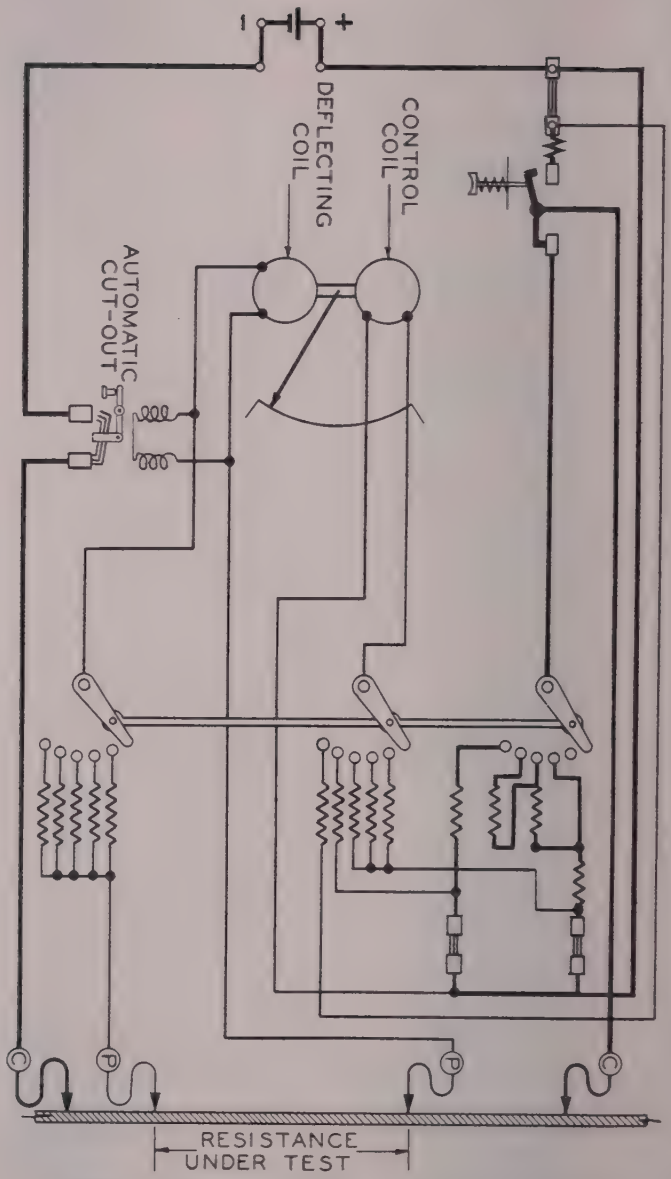

FIGURE 13. Schematic circuit diagram for Cat. 713 "Ducter" Low Resistance Ohmmeter.

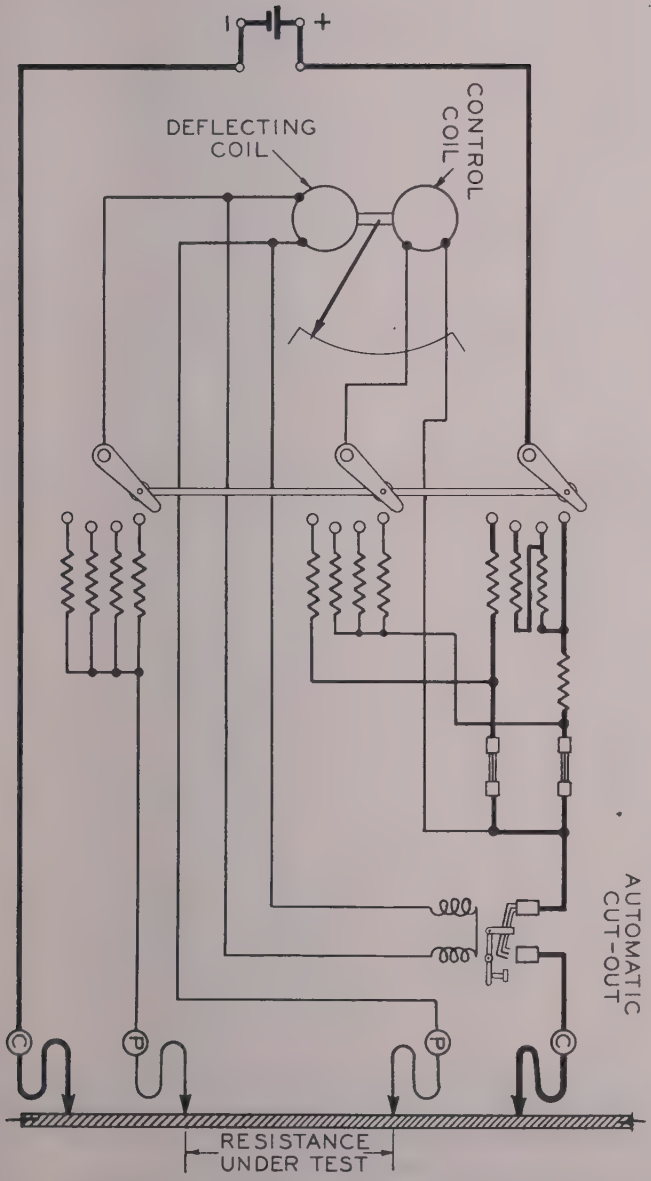

FIGURE 14. Schematic circuit diagram for Cat. 714 "Ducter" Low Resistance Ohmmeter.

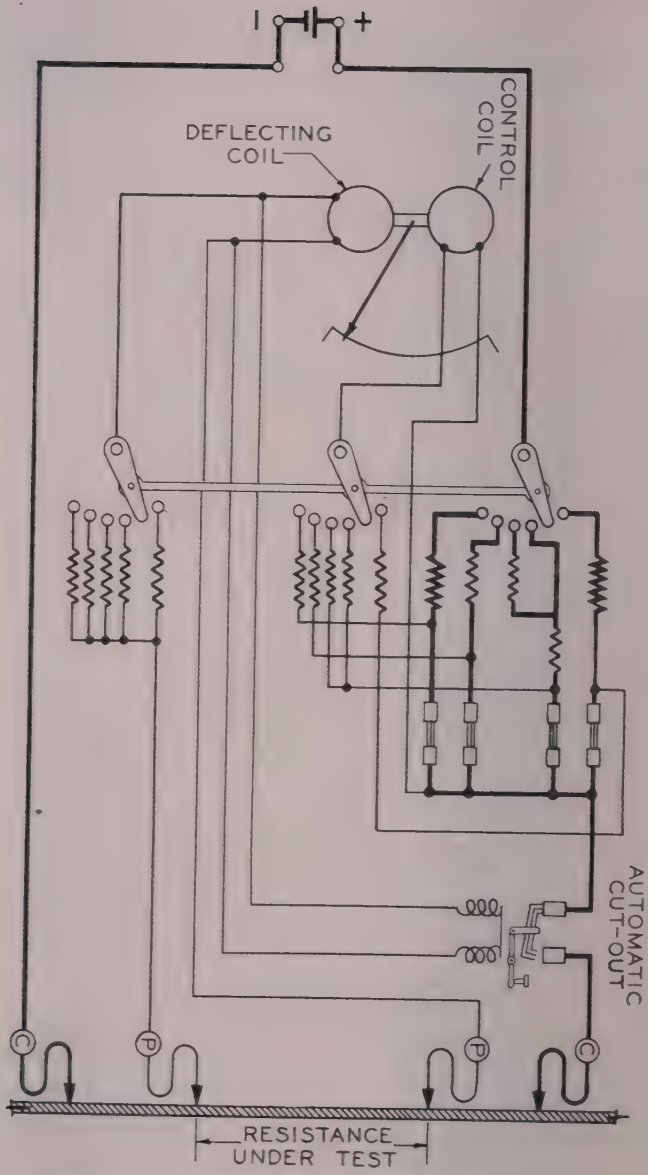

FIGURE 15. Schematic circuit diagram for Cat. 718 "Ducter" Low Resistance Ohmmeter.

Section VIII

RESISTANCE NETWORK DATA

The following passive resistance networks are those which may be encountered in simple circuits, and such equipment as multi-conductor cables, three-phase transformers, and a-c generator armatures.

The Series Network:

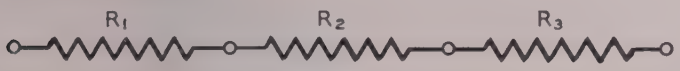

FIGURE 16.

$$\text{Total } R = R_1 + R_2 + R_3 + \cdots\cdots\cdots\cdots R_n$$

The Parallel Network:

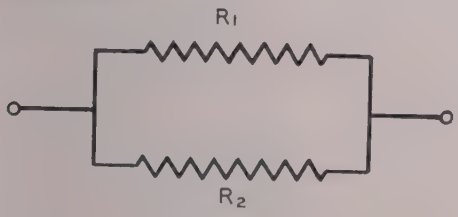

FIGURE 17.

$$\text{Total } R \text{ for two paths} = \frac{R_1 R_2}{R_1 + R_2}$$

$$\text{Total } R \text{ for three paths} = \frac{R_1 R_2 R_3}{R_1 R_2 + R_2 R_3 + R_3 R_1}$$

$$\text{Total } R \text{ generalized} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots\cdots \frac{1}{R_n}}$$

The Star Network:

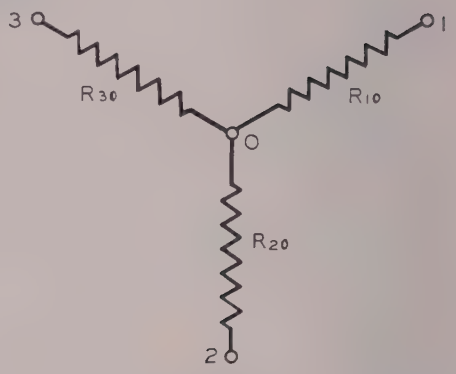

FIGURE 18.

$$R_{10} = \frac{R_{12} - R_{23} + R_{31}}{2}$$

$$R_{20} = \frac{R_{12} + R_{23} - R_{31}}{2}$$

$$R_{30} = \frac{R_{31} - R_{12} + R_{23}}{2}$$

The Delta Network:

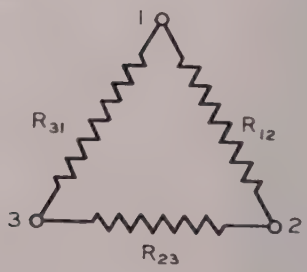

FIGURE 19.

M = Measurement between two terminals of a closed delta network.

$$N = \text{Numerator}$$
$$= 2M_{12}M_{23} + 2M_{23}M_{31} + 2M_{31}M_{12} - [(M_{12})^2 + (M_{23})^2 + (M_{31})^2].$$

$$M_{12} = \frac{R_{12}\ (R_{23} + R_{31})}{R_{12} + R_{23} + R_{31}} \qquad R_{12} = \frac{N}{2M_{31} + 2M_{23} - 2M_{12}}$$

$$M_{23} = \frac{R_{23}\ (R_{12} + R_{31})}{R_{12} + R_{23} + R_{31}} \qquad R_{23} = \frac{N}{2M_{31} + 2M_{12} - 2M_{23}}$$

$$M_{31} = \frac{R_{31}\ (R_{12} + R_{23})}{R_{12} + R_{23} + R_{31}} \qquad R_{31} = \frac{N}{2M_{12} + 2M_{23} - 2M_{31}}$$

It is sometimes desirable to check the resistance of a complete delta network that cannot readily be opened, such as the delta winding in a three-phase power transformer, or a three-phase generator or motor armature. In such cases, M_{12}, M_{23}, and M_{31} should be equal if R_{12}, R_{23}, and R_{31} are equal. If not, the individual legs of the delta network may be unbalanced.

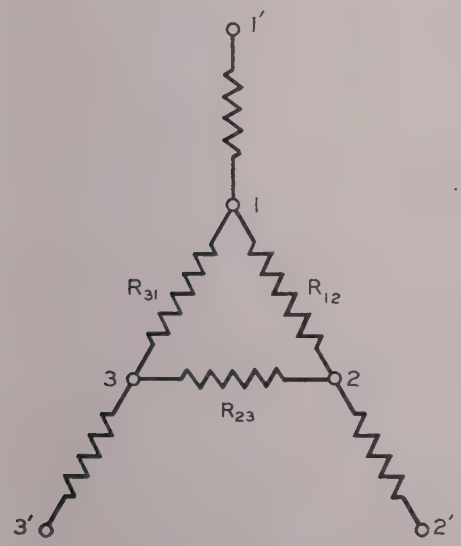

FIGURE 20.

Figure 20 shows such a network including cable resistances from each delta point to the terminals of the apparatus under test. If the three points of the delta are accessible then the values of the three individual leg resistances, R_{12}, R_{23}, and R_{31}, may be calculated from data obtained by making a "Ducter" Instrument test as shown in Fig. 21.

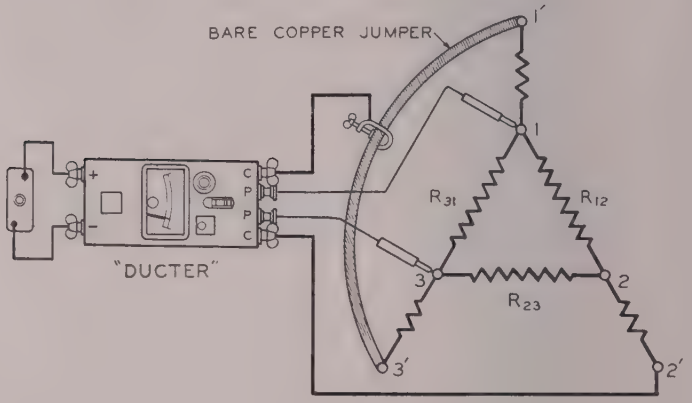

FIGURE 21.

The test data necessary to make the calculations are obtained as follows:

First, measure the resistance R_{12} and R_{23} in parallel. This is done by short-circuiting R_{31} with a bare, low resistance, copper jumper, and connecting one of the current terminals of the "Ducter" Instrument to the 2′ point of the delta, and the other current terminal to the jumper at a point midway between 1′ and 3′ points of the delta.

Apply the potential prods to the 1 and 3 points of the delta and slide the current connection on the jumper until a zero reading is obtained. Use the lowest range of the "Ducter" Instrument to obtain this zero balance.

The potential prods are then applied to the 2 and 3 points, or the 1 and 2 points, of the delta, and the parallel resistance of R_{12} and R_{23} measured.

The foregoing procedure is then repeated for the other two sides of the delta. Make sure that the potential prods are applied to the points of the delta in each case, and not to the extensions of these points.

Let:

M_{123} = the resistance of R_{12} and R_{13} in parallel
M_{231} = the resistance of R_{23} and R_{31} in parallel
M_{312} = the resistance of R_{12} and R_{31} in parallel

Then:

$$R_{31} = \frac{2\,(M_{123}\,M_{231}\,M_{312})}{M_{123}\,M_{231} + M_{231}\,M_{312} - M_{123}\,M_{312}}$$

$$R_{23} = \frac{2\,(M_{123}\,M_{231}\,M_{312})}{M_{123}\,M_{312} + M_{123}\,M_{231} - M_{231}\,M_{312}}$$

$$R_{12} = \frac{2\,(M_{123}\,M_{231}\,M_{312})}{M_{123}\,M_{312} - M_{123}\,M_{231} + M_{231}\,M_{312}}$$

Section IX

TEMPERATURE DATA

Resistance Values Corrected for Temperature

When making accurate comparisons of resistances under test their temperatures must be considered, since the resistances of all metals are greatly affected by temperature. Where accuracy is important the most practical method is to measure the temperature of the resistance under test, and determine by calculation the resistance at the temperature desired. The mathematical formula for 100% conductivity copper is:

$$R_1 = R_2 \frac{T_1 + 234.5}{T_2 + 234.5}$$

where—

R_1 = Resistance at desired temperature T_1.
R_2 = Resistance measured at time of test.
T_1 = Temperature in degrees C at R_1.
T_2 = Temperature in degrees C at time of test.

Determining Temperature from Resistance Measurements

Very often the most practical means of determining the average temperature of electrical equipment is to measure the resistance of certain conductors within the equipment, and calculate the average temperature when the conductor resistance at a known temperature has been first established. This is often done to determine the temperature of armatures and fields in rotating equipment, the temperature of cables, and the temperature of transformer windings. See Technical Bulletin No. 21T4, pages 11 and 12.

The mathematical formula for this calculation is:

$$T_2 = \frac{R_2}{R_1}(234.5 + T_1) - 234.5$$

Where—

T_2 = Temperature in degrees C desired at time of test.

T_1 = Known temperature in degrees C at R_1.

R_1 = Resistance at known temperature T_1.

R_2 = Resistance measured at time of test.

R_1 should be determined at such time as the equipment has been idle under constant ambient temperature condition for a time sufficiently long to be sure that T_1 is the same as the ambient temperature. This information might be obtained from the manufacturer of the apparatus, or from the original factory test report. Of course, it must be remembered that conditions such as defective joints or contacts may affect the total resistance at the same temperature.

Since the Wheatstone bridge is not particularly accurate for measuring resistances below one ohm, and since most large electrical equipment have winding and conductor resistances much lower, the "Ducter" Low Resistance Ohmmeter is often used for resistance measurements of this kind.

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